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# Frequency discrimination of deaf children and its relationship to their achievement in auditory training.

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# FREQUENCY DISCRIMINATION OF DEAF CHILDREN AND ITS RELATIONSHIP TO THEIR ACHIEVEMENT IN AUDITORY TRAINING

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Table of Contents

## Introduction

The question of frequency discrimination has been studied for many years and by many different methods (1). The fundamental problem of determining the range of frequencies which are audible was soon supplemented by the problem of differential perception. As early as 1700, experiments were made to determine just how many tonal differences are discriminable within the audible range.

Stevens (13) sums up the methodological techniques employed in the determination of the differential threshold for frequency prior to 1951 with the statement, "Probably the best procedure would be to vary the dial of an oscillator smoothly (sinusoidally) back and forth between two frequency settings and determine how far apart the settings have to be to make the average listener report 'change' in half the trials." The "frequency modulation" technique is represented by the early work of Knudsen (11) and by Shower and Biddulph (12). Knudsen's work was replicated by Youtz (14) using a larger N and extending the range of frequencies examined. A methodological distinction existed between the above mentioned studies in that Knudsen and Youtz changed frequencies quite abruptly whereas Shower and Biddulph periodically changed the frequency of the test tone in a way that would be achieved if the oscillator dial were moved sinusoidally from one frequency to the other and then allowed to rest a moment before being moved back.

In general, the results of the above mentioned studies indicate that the relative DL for frequency remains constant at about 0.003 as the frequency is increased above 1000 cps. This means that at 1000 cps the normal ear can detect a change in frequency of about 3 cps, and at 5000 cps cannot detect a change of less than 15 cps.

Recently, in a series of papers concerning methodological rationale and experimental findings, Harris (4,5) has argued that a more valid picture of the frequency discrimination of the human auditory system is given when two tones are separated in time when being compared with respect to pitch. Harris (5) slightly modifies the standard psychophysical technique of "Constant Stimuli Differences" and reports data differing somewhat from the data obtained by approximately sinusoidal frequency modulation (Shower and Bidduplh). Harris' DL's for frequency were somewhat smaller at the lower frequencies than those obtained by workers employing the frequency modulation method and he concludes that for frequencies below 1000 cps the two methods explore quite different psychological functions.

While various individuals have been working with difference limens for frequency examinations on normal ears for more than two centuries, DLF examinations on "deaf" ears have been going on for only the last several years with most of the few studies conducted stemming from European workers.

Filling (2) presented a paper to the World Conference of the Deaf in Yugoslavia outlining her own work in Denmark on the Audiometrical Measurement of Difference Limen for Frequency in Pathological Ears. Sinusiodal frequency - modulated tones were judged by S's representing various degrees of hearing loss who fell into three groups according to the etiology of the hearing disease:

1. Perceptive type

2. Mixed perceptive-conductive type

3. Conductive type

The above three types range from the most severe degree of hearing loss of the perceptive type to the least amount of hearing loss of the conductive type, although no mention was made of the actual amount of hearing loss represented in each category. The DLF's obtained were read directly in percentage of the standard frequency used and were also converted to absolute values, F, expressed in cps. In conclusion she states, "the results of the DLF examinations of pathological ears show beyond any doubt that pure or mainly conductive types of hearing disease have normal or slightly increased DLF audiograms, while perceptive or mixed perceptive-conductive types show a pronounced increase in proportion with the part played by the perceptive element in the hearing disease".

Hudgins (10) in the Eighty-eighth Annual Report of the Clarke School for the Deaf reports an effort made to shed some light on the problems of individual differences in "deaf" children in regard to their auditory speech perception ability. An attempt was made to demonstrate that children even with severe hearing losses may differ with respect to their abilities in frequency discrimination and thus that this may possibly be a factor accounting for individual differences in speech perception. A preliminary survey of frequency discrimination was made on predominately profoundly deaf children, the results of which demonstrated that they were able to make frequency discriminations, but with thresholds of discrimination very large as compared to that of normal hearing subjects. The group of S's studied differed widely in their responses and only a slight correlation was found between the degree of hearing loss and frequency discrimination. Furthermore, no apparent relationship was found between frequency discrimination ability and response to auditory training as measured by speech perception tests. Personal communication with the author indicates that failure to find the above mentioned relationship between frequency discrimination and speech perception ability may possibly be due to the inadequacy of the methods available at the time.

The present study is primarily an attempt to measure the frequency discrimination ability for pure tones of a population group of deaf children. This measurement was attempted by use of standard psychophysical technique.

In addition the relationship between the relative ability to discriminate frequency differences of pure tones with the degree of hearing loss as measured by the minimum audible threshold for intensity of pure tones was studied. Each of the S's minimum audible threshold for intensity of pure tones was determined by audiometric measurement.

Finally, in addition to an attempt at psychophysical quantification of a relatively unexplored population, an attempt was made to indicate the value of this knowledge in regard to practical considerations in the education of the deaf. The above stated measurement of the "deaf's" ability to discriminate frequency together with knowledge of their hearing loss should shed some light on the deaf individual's ability to use and derive benefit from "auditory training". Auditory training as discussed by Hudgins (7) is, in general, the training of the deaf to make the most effective use of whatever amount of residual hearing they may possess with the results of this training evaluated by some measure of auditory speech perception. It is generally understood that frequency discrimination plays an important role in auditory speech perception and an attempt was made to determine the extent of this relationship in "deaf" ears.

## Method

Subjects.-- Twenty deaf students attending the Clarke School for the Deaf were studied. Seventeen of the S's are classified as "profoundly" deaf (80 db loss for pure tones or greater) and three are classified as "partially"deaf (60 to 80 db loss for pure tones). The S's ranged from 14 to 17 years of age.

Ten "normal" hearing S's from the Teacher Education Program at Clarke School were used to establish a normal sensitivity threshold curve for pure tones.

Stimuli and Apparatus.-- The stimuli for both the measurement of absolute thresholds for intensity and difference limens for frequency were pure tones. Threshold measurements were made for seven frequencies: 125, 250, 500, 1000, 2000, 4000 and 8000 cps. Measurement of DL's for frequency were made for three standard frequencies: 500, 1000 and 2000 cps.

The apparatus used for threshold measurements was a General Radio beat-frequency oscillator, a vacuum tube A.C. voltmeter, a matching transformer, a 5 watt 500 cps attenuator set, an interrupter cut-off switch and a calibrated Permaflux (Dynamic) PDR-10 headphone fitted with a sponge rubber cushion MX-41/AR. A block diagram of the apparatus used for threshold measurement is shown in Figure 1.

The apparatus for DL's for frequency discrimination included the above with an additional R-C Oscillator (Hewlet Packard 200 AB), an amplifier (Fairchild-Procter 219) and a Grayson-Stadler Electronic Switch. A block diagram of the equipment used in the frequency discrimination measurements is shown in Figure 2.

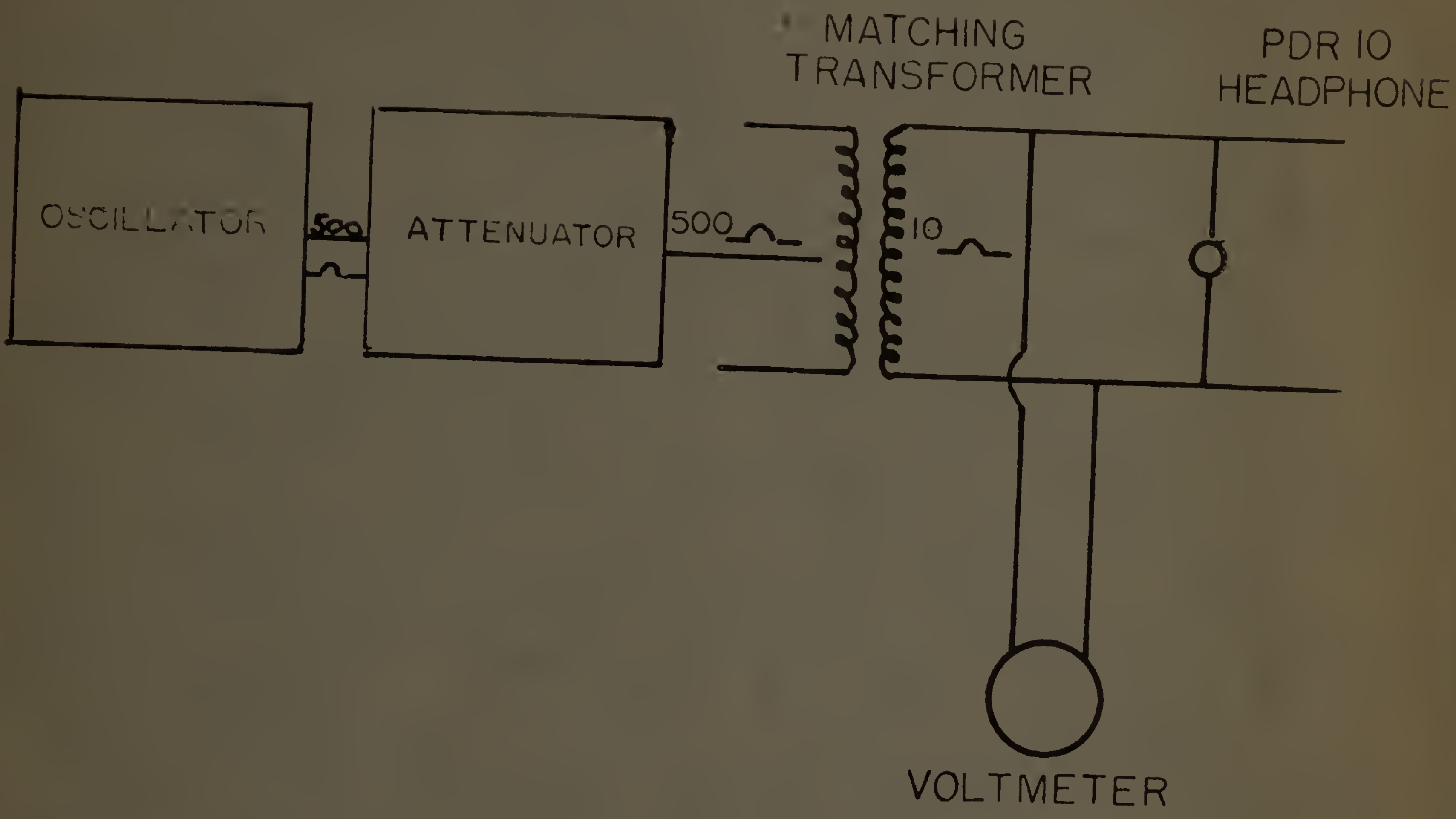


Fig. 1. Block diagram showing arrangement of equipment for measurement of pure tone threshold.

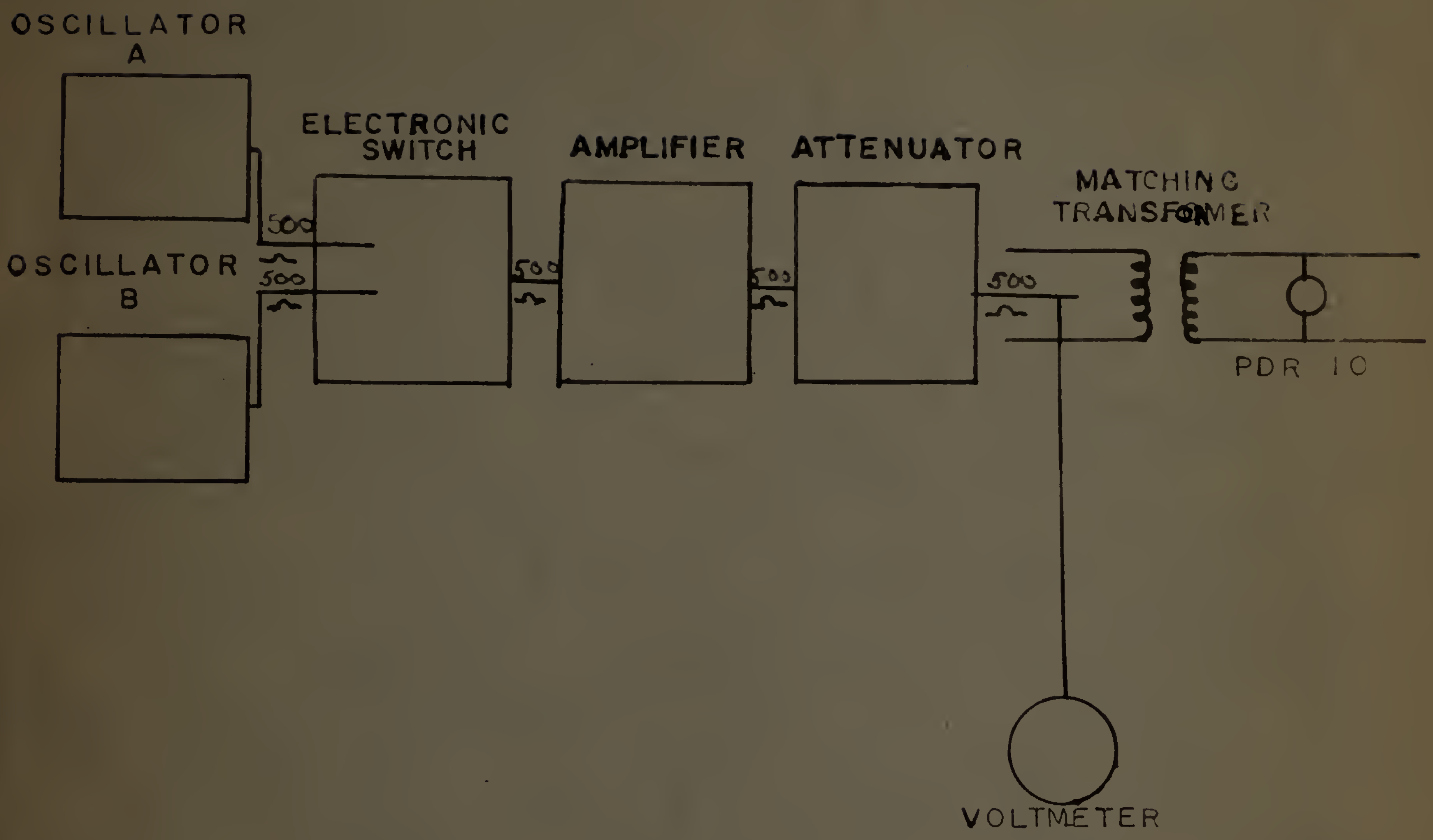


Fig. 2. Block diagram showing arrangement of equipment for measurement of frequency discrimination.

Procedure for measuring absolute thresholds for pure tones.-- The S's thresholds for the seven pure tones enumerated above were measured by the standard psychophysical of "limits". E manipulated the attenuator, gradually decreasing the intensity of a tone well above threshold to the point when S first indicated he no longer perceived the tone. E then gradually increased the intensity of a tone from well below threshold to the point when S first indicated that he perceived it. S indicated these judgments by means of depressing and releasing a hand switch which was connected to a light indicator. The absolute threshold for each tone was determined in the conventional way. The median value of the judgments when S first perceived the tone and the median value of the judgments when S first indicated he no longer perceived the tone were computed. The mean of these two values were used as the absolute threshold.

The deaf S's hearing loss, in decibels, for pure tones was computed by comparison with the average normal sensitivity curve obtained for the ten normal hearing S's. This "normal" threshold curve was determined statistically by audiological measurement utilizing the same apparatus and procedure described above.

Procedure for measuring difference limens for frequency. Measurement of DL's for frequency was made by a modification of the psychophysical method of "constant stimuli differences". The output of two oscillators was led to the two input terminals of an electronic switch capable of keying the onset of the tone from one oscillator, passing the tone for approximately two seconds, then terminating it while alternately keying the onset of a tone from the second oscillator with the same time characteristics. The two oscillators were alternately keyed on and terminated by the electronic switch which eliminated audible transients by the use of appropriate rise and fall times for stimulus onset and termination respectively. One of the oscillators maintained a fixed tone (standard) while the other presented a number of comparison frequencies (test tones). The order of presentation of the various comparison tones with the standard was random. A zero time interval between the presentation of the two tones was used, each tone being approximately two seconds in duration. S was permitted to listen to each pairing of the alternating test and standard tones until a judgment of "same" or "different" was made. The number of presentations necessary for each subject of the standard and test tones was determined experimentally. This was necessary because each subject presented a unique problem in respect to frequency discrimination ability. It was first necessary to establish for each subject a frequency discrimination range; i.e., the frequency range below which all judgments were "same" and above which all judgments were "different". This range differed widely from subject to subject. Once established it was possible to divide this range into discrete frequency steps to be employed as test tones. The relative consistency of an S's judgments determined the number of presentations necessary for a stable threshold. The intensity of the tones for frequency discrimination was set at 15 db above the S's absolute threshold for the particular frequency. In order to eliminate the possibility of receiving cues for his judgments by observation of the equipment itself the S was seated with his back to the equipment and the experimenter. The DL's for frequency were determined by the graphic method.

Procedure for measuring auditory speech perception.-- The profoundly deaf are unable to distinguish words by audition alone, thus an indirect measure of auditory speech perception must be calculated. The method used, as described by Hudgins (8, pp. 276-279) is the standard procedure employed annually at the Clarke School for the Deaf as part of a continuous program of studying achievement in auditory training. The word lists used in the tests have been presented by Hudgins (9, p. 638). The measure of auditory speech perception is the difference in score a deaf S achieves while attempting to distinguish standard words when only "looking" (lip-reading) as compared to "looking and listening". The scores are in terms of the per cent of words from standard lists correctly perceived. The difference between the "look" score and the "look and listen" score is attributed to the auditory component of the sensory stimuli. The above described auditory speech perception scores were obtained for the twenty deaf S's as a part of the routine annual testing program at Clarke School.

## Results

The results of the audiometric tests to determine the hearing loss and the frequency discrimination ability of the deaf subjects are presented below.

Hearing Loss.-- The average hearing loss of the twenty subjects for the three major speech frequencies (500, 1000 and 2000 cps) ranged from a 69 db loss for the S with the least loss to a 101 db loss for the S with the greatest loss. The hearing losses for each of the S's for 500, 1000 and 2000 cps along with the average hearing loss are shown in Appendix 1. The range of hearing loss at 500 cps was from a 59 db loss to an 89 db loss with the mean loss being 70 db. At 1000 cps the range of hearing loss was from 74 db to 104 db with a mean loss of 94 db. At 2000 cps the range was from a 60 db loss to a 120 db loss the mean loss being 101 db.

Hearing loss, in decibels, for pure tones was computed by comparing the deaf S's sensitivity durve with the average normal sensitivity curve obtained from ten normal hearing S's. Figure 3 shows the average normal sensitivity curve used in the present study along with the sensitivity curve of a typical deaf subject. The average curves of the thresholds of "Discomfort" and "Tickle" for normal ears as measured at the Central Institute for the Deaf (6) is also presented.

Difference Limens for Frequency and a Measure of Their Variability.-- Measurement of DL's for frequency were made for the twenty S's at 500 cps, nineteen S's at 1000 cps and twelve S's at 2000 cps. DL's for frequency could not be obtained at these three frequencies for eight S's. This was

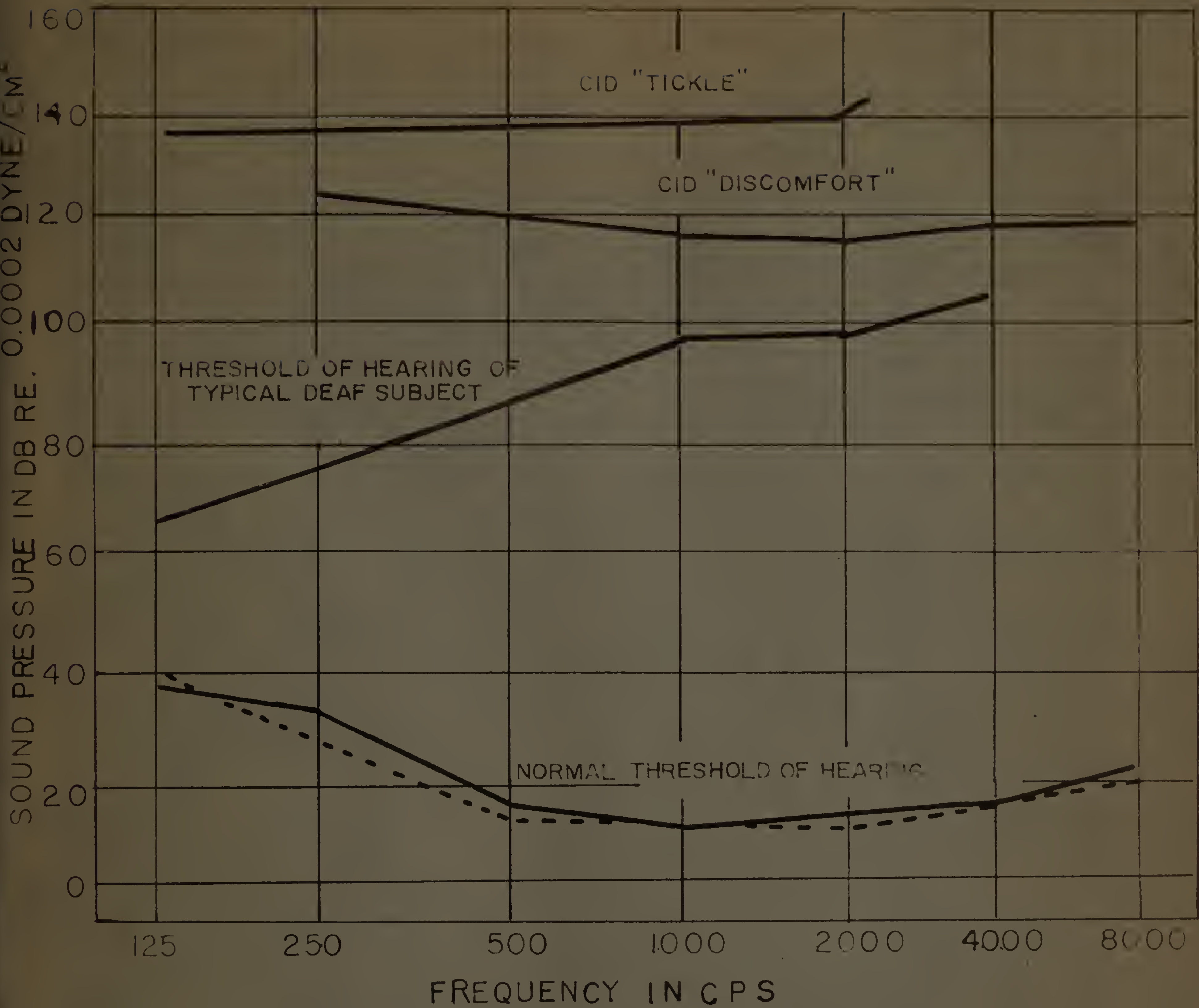


Fig. 3. The average normal threshold contour (10 subjects) used to establish degree of hearing loss in the present study is shown at the bottom of the figure. The broken line represents for comparison the curve of minimum audible pressure taken from Sivian and White (6). The two curves are not exactly comparable, however, the values of the present study represent pressures under the receiver of the PDR-10 headphone, fitted with a sponge rubber cushion MX-41/AR, and Sivian and White's data include a correction to give the acoustic pressure at the eardrum. The center contour shows the threshold for a typical deaf S and the upper curves are Central Institute for the Deaf's thresholds of "Discomfort" and "Tickle".

due to the fact that the hearing loss for these S's was so great as to make it impossible to increase the intensity of the tone above their absolute thresholds to the point necessary for making frequency discrimination judgments without first reaching the threshold of feeling. The DL's for frequency have been converted to Weber fractions which is the ratio of the frequency difference necessary to be judged as "different" 50 per cent of the time to the standard frequency $\frac{\text{diff. frequency}}{\text{standard frequency}}$. At 500 cps the Weber fraction ranged from .02 to .30 with the mean at .11. The range at 1000 cps was from .01 to .20 with a mean of .09. At 2000 cps the range was from .01 to .09 with the mean being .05. Table 1 shows frequency discrimination data for 500, 1000 and 2000 cps.

The variability of the S's judgments for each DL for frequency was measured by the semi-interquartile range or Q. Figure 4 represents diagramatically the nature of Q as a measure of variability about the DL. It is based upon the degree of steepness of the slope of the standard psychophysical curve from which the DL's for frequency were graphically derived. The ordinate of the graph is in terms of per cent of judgments of "different" and the abscissa in terms of frequency differences in cps. The point at which 50 per cent of the judgments are "different" is taken as the DL for frequency. The semi-interquartile range or Q may be defined as: $\frac{Q_3 + Q_1}{2}$, where $Q_3$ is the point below which 75 per cent of the judgments fall and $Q_1$ is the point below which 25 per cent of the judgments fall. Two right triangles are thus formed whose sides are a, b, and h and $a^1$, $b^1$, and $h^1$. The semi-interquartile range is thus the ratio $\frac{a + a^1}{2}$, where a and $a^1$ vary as a function of the degree of variability of a particular S's judgments. Table 2 presents

Table 1

Frequency Discrimination in Terms of Webers Fraction at 500, 1000, and 2000 cps and Their Q Measure of Variability Expressed in Terms of the Ratio of Q to the Standard Frequency for Twenty Deaf Subjects

| Subject Number | 500 cps DLF (Weber Fraction) | 500 cps Q Variability | 1000 cps DLF (Webers Fraction) | 1000 cps Q Variability | 2000 cps DLF (Webers Fraction) | 2000 cps Q Variability |
|---|---|---|---|---|---|---|
| 1 | .03 | .01 | .07 | .01 | .02 | .01 |
| 2 | .03 | .01 | .02 | .01 | .05 | .01 |
| 3 | .02 | .01 | .01 | .01 | .02 | .01 |
| 4 | .11 | .02 | .16 | .07 | --- | --- |
| 5 | .10 | .02 | .20 | .06 | .03 | .01 |
| 6 | .08 | .01 | .06 | .01 | --- | --- |
| 7 | .08 | .02 | .04 | .02 | --- | --- |
| 8 | .05 | .01 | .20 | .06 | .06 | .04 |
| 9 | .15 | .07 | .07 | .03 | --- | --- |
| 10 | .04 | .01 | .05 | .01 | .09 | .02 |
| 11 | .12 | .02 | .04 | .01 | --- | --- |
| 12 | .16 | .06 | .15 | .05 | .02 | .01 |
| 13 | .12 | .02 | .10 | .03 | .06 | .01 |
| 14 | .10 | .03 | .04 | .03 | --- | --- |
| 15 | .15 | .04 | .11 | .02 | --- | --- |
| 16 | .18 | .03 | .09 | .01 | .05 | .01 |
| 17 | .30 | .07 | .12 | .01 | .08 | .01 |
| 18 | .27 | .01 | .11 | .01 | .05 | .01 |
| 19 | .10 | .02 | --- | --- | --- | --- |
| 20 | .08 | .02 | .06 | .01 | .01 | .01 |
| Mean | .11 | | .09 | | .05 | |
| Standard Deviation | .07 | | .05 | | .02 | |

the measure of variability of each of the DL's for frequency as determined by the semi-interquartile range. The variability is expressed as a ratio of the Q to the standard frequency $\frac{Q}{\text{standard frequency}}$.

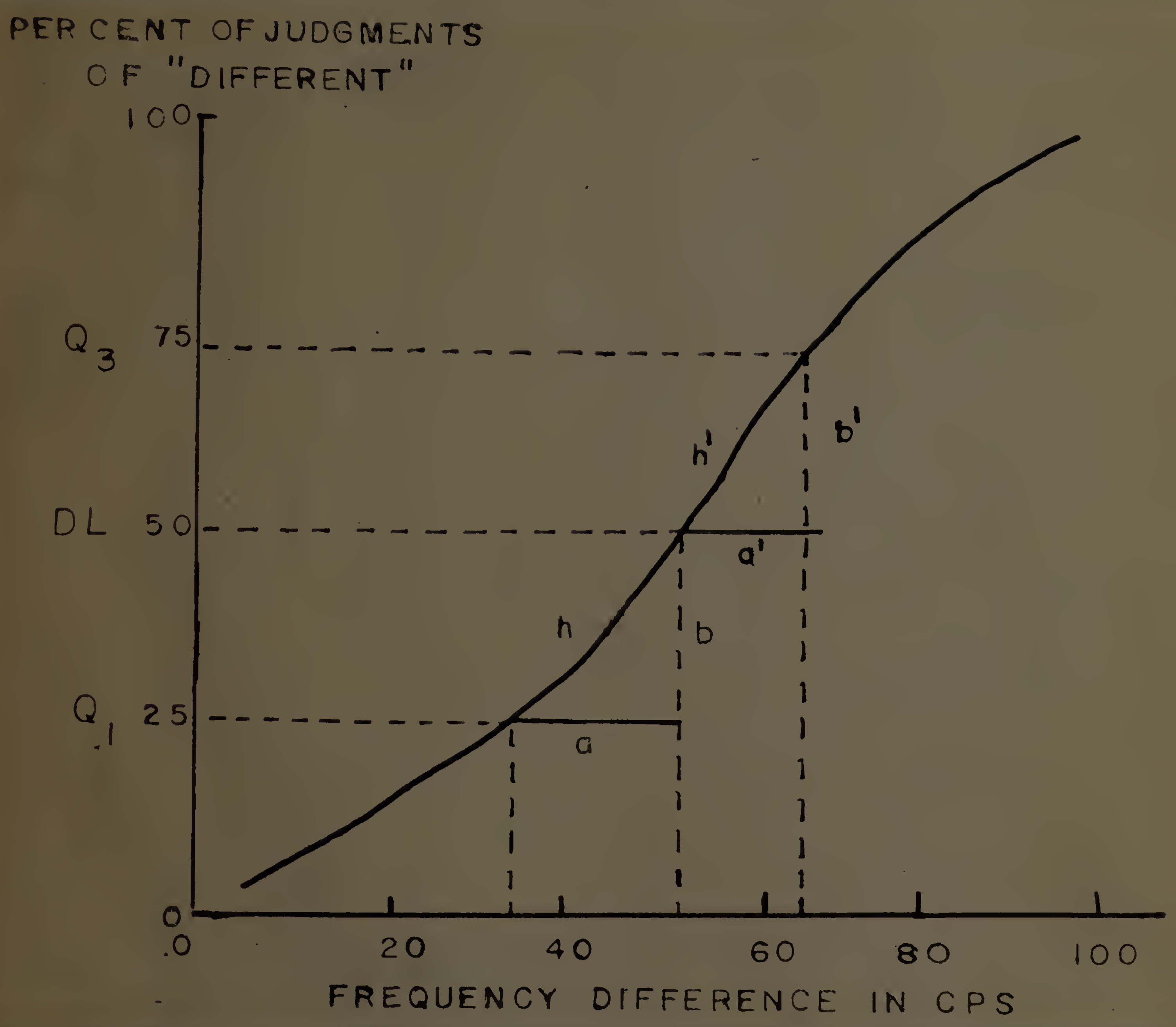


Fig. 4. The nature of Q (semi-intequartile range) as a measure of variability about the DL for frequency.

Auditory Speech Perception.-- Measures of auditory speech perception were obtained for each of the twenty S's. The measure of auditory speech perception is the difference between scores for "Look and Listen" (lip-reading and listening) and those for lip-reading alone. The "Look and Listen", the lip-reading score and the "Difference" (auditory component of speech perception) for each of the twenty S's is shown in Appendix 2. The "Look and Listen" scores ranged from a high of 92 to a low of 56, the highest lip-reading score was 64 and the lowest 50 thus yielding "Difference" scores ranging from a high of 28 to a low of 6. The scores are in terms of the per cent of words from standard lists correctly perceived (9).

Correlation of the Degree of Hearing Loss to Difference Limens for Frequency.-- Pearson product-moment correlations were computed relating each of the S's hearing loss at 500 cps to their DL's for frequency at 500 cps, their hearing loss at 1000 cps to their DL's for frequency at 1000 cps and hearing loss at 2000 cps to DL's for frequency at 2000 cps. The correlations of hearing loss to frequency discrimination ability are shown in Table 2. No statistically significant correlations were found relating the degree of hearing loss, for a particular frequency, to frequency discrimination ability at that frequency.

Table 2

Pearson Product-Moment Correlations of the Degree of Hearing Loss to Difference Limens for Frequency at 500, 1000, and 2000 cps.

| Frequency | Number of Subjects | r | PE | "t" Value | Probability |
|---|---|---|---|---|---|
| 500 | 19 | .35 | .14 | 1.53 | .2 |
| 1000 | 18 | .35 | .14 | 1.49 | .2 |
| 2000 | 12 | .13 | .17 | .47 | .6 |

Correlation of the Degree of Hearing Loss to the Auditory Speech Perception Scores (L & L - L).-- Separate Pearson product-moment correlations were computed relating the S's hearing loss at 500, 1000, 2000 and 4000 cps to their auditory speech perception scores. A coefficient of correlation was also computed relating the average hearing loss for the three major speech frequencies (500, 1000 and 2000 cps) to the auditory speech perception scores. Table 3 shows the correlation data of hearing loss to auditory speech perception. Statistically significant negative correlations were found at 1000, 2000 (.01 level) and 4000 cps (.05 level).

Table 3

Pearson Product-Moment Correlations of the Degree of Hearing Loss For 500, 1000, 2000, 4000 cps and the Average Hearing Loss Score To Auditory Speech Perception Scores

| Frequency | Number of Subjects | r | PE | "t" $V_a$lue | Probability |
|---|---|---|---|---|---|
| 500 | 19 | -.17 | .15 | .72 | .50 |
| 1000 | 19 | -.59 | .10 | 2.99* | .01 |
| 2000 | 18 | -.75 | .07 | 4.55* | .01 |
| 4000 | 19 | -.46 | .13 | 2.14** | .05 |
| Average | 18 | -.21 | .16 | .90 | .40 |

* Significant at .01 level
** Significant at .05 level

Correlation of Difference Limens for Frequency to the Q Measure of Variability of the DL's.-- Separate Pearson product-moment correlations were computed rela ting the S's DL's for frequency to the Q measure of variability of each DL at 500, 1000 and 2000 cps. Table 4 shows the correlation data between DL's for frequency and the Q measure of their variability. Statistically significant correlations were found between DL's for frequency and their Q measures of variability at 500, 1000 (.01 level) and 2000 cps (.05 level).

Table 4

Pearson Product-Moment Correlations of Difference Limens for Frequency and Their Q Measures of Variability for 500, 1000 and 2000 cps

| Frequency | Number of Subjects | r | PE | "t" Value | Probability |
|---|---|---|---|---|---|
| 500 | 19 | .65 | .09 | 3.53* | .01 |
| 1000 | 18 | .83 | .05 | 5.93* | .01 |
| 2000 | 12 | .57 | .14 | 2.23** | .05 |

* Significant at .01 level
** Significant at .05 level

<u>Correlation of Difference Limens for Frequency to the Auditory Speech Perception Scores</u> (<u>L & L - L</u>).-- Separate Pearson product-moment correlations were computed relating the S's DL's for frequency at 500, 1000 and 2000 cps to their auditory speech perception scores. Table 5 shows the relationship between DL's for frequency and auditory speech perception. A statistically significant negative correlation (.01 level) was found between DL's for frequency at 500 cps and auditory speech perception scores.

Table 5

Pearson Product-Moment Correlations of the Difference Limens for Frequency For 500, 1000 and 2000 cps to Auditory Speech Perception Scores

| Frequency | Number of Subjects | r | PE | "t" Value | Probability |
|---|---|---|---|---|---|
| 500 | 19 | -.71 | .08 | 4.16* | .01 |
| 1000 | 18 | -.39 | .14 | 1.69 | .15 |
| 2000 | 12 | -.30 | .19 | .99 | .35 |

* Significant at .01 level

Multiple Correlation of the Degree of Hearing Loss and Frequency Discrimination Ability to Auditory Speech Perception.-- Multiple correlations were computed for each of the three frequencies examined, 500, 1000 and 2000 cps, relating hearing loss and DL's for frequency to the auditory speech perception score of each S. The multiple r indicates the strength of the correlation between one variable and two other variables taken together and is not merely the sum of correlations taken separately. The independent variables of hearing loss and DL's for frequency have been simultaneously correlated to the dependent variable which is the auditory speech perception scores. The data for the multiple r's relating hearing loss and DL's for frequency to auditory speech perception is presented in Table 6. Although the multiple r's were high for all three frequencies after a correction for bias was made (necessary for small samples) only at 1000 and 2000 cps were statistically significant negative correlations found (.05 level).

Table 6

Multiple Correlation of Degree of Hearing Loss and Frequency Discrimination Ability to Auditory Speech Perception

| Frequency | Number of Subjects | Multiple r | Multiple r (Corrected for bias) | PE | Multiple r Sign. at 5 Per Cent Level |
|---|---|---|---|---|---|
| 500 | 19 | -.60 | -.52 | .12 | .56 |
| 1000 | 18 | -.64 | -.57** | .11 | .57 |
| 2000 | 12 | -.78 | -.72** | .08 | .70 |

** Significant at .05 level

## Discussion

A measure of frequency discrimination would appear to be an important factor in any attempt to appraise the quality of the hearing remnant that a deaf individual possesses other than the actual severity of the deafness as measured by the pure tone audiogram. In the area of auditory training of deaf children it would seem that knowledge of a pupil's frequency discrimination ability would be an important datum which could possibly shed some light on the problem of the rather broad range of individual differences which are found in response to auditory stimulation.

### Hearing Loss and Frequency Discrimination Ability

The present study demonstrates that some "deaf" children can make frequency discriminations for pure tones and that their difference limens for frequency can be measured by modification of standard psychophysical technique. The thresholds of discrimination of the "deaf" subjects are very large as compared to that of hearing subjects who obtain Weber fractions as small as 0.003. S's studied differed widely in their frequency discrimination ability. It was found that the Q measure of variability of the S's DL's for frequency varies inversely with frequency discrimination ability; i.e., the smaller the DL the less variable were the S's judgments.

No significant correlations were found between degree of hearing loss and the ability to discriminate frequency at any of the three frequencies studied. This indicates that frequency discrimination ability is not a direct function of the severity of deafness. It is clearly seen that some S's with greater hearing losses for pure tones do better in discriminating frequency than others with less severe losses. This seems to indicate that qualitative differences exist in the small remnants of hearing which may appear equal as measured by the audiogram.

The fact that no significant correlations were found between hearing loss and frequency discrimination can perhaps be understood by an examination of the sample under study. The sample consists of severely damaged ears (17 of the 20 S's being profoundly deaf). Thus it would fall on the lower end of any continuum ranging from normal hearing to complete deafness. Therefore, this sample representing only the extreme opposite end of a continuum anchored to normal hearing could not possibly demonstrate any relationship which might exist between the entire range of hearing loss and frequency discrimination. It would thus seem that a true picture of the relationship between hearing loss and frequency discrimination could only be obtained by a sample utilizing the range of hearing loss from normal hearing to complete deafness and not the extreme end of this range as has been the case in the present study. However, within the sample studied there is evidence that frequency discrimination ability varies independently of the magnitude of the hearing remnant. This fact suggests qualitative differences in the remnant. The basis for these differences must lie in the physiological status of each particular subject's ear, and have not been revealed by the methods employed in this study. Further investigation in which frequency discrimination for a group possessing a wider range of hearing loss and studies of intensity discrimination may prove fruitful.

Hearing Loss and Auditory Speech Perception

Statistically significant negative correlations (.01 level) were found to exist between the degree of hearing loss, at 1000, 2000, and 4000 cps and the auditory speech perception scores. Thus, those S's whose hearing loss for pure tones is less severe at 1000, 2000 and 4000 cps make higher scores in speech perception than those S's whose loss in hearing acuity is greater at these frequencies. As expected this seems to indicate that the less severe the deafness at the higher frequencies, the more usable is the remnant for auditory speech perception.

That the higher frequencies play a more important role than the low frequencies in auditory speech perception seems to be demonstrated by the fact that no significant correlation was found between hearing loss at 500 cps and the auditory speech perception score. These results agree with French and Steinberg (3), who studied the relative contribution to speech perception of the different frequencies contained in a normal speech sample. They found that frequencies below 500 cps contributes only about 5 per cent of the intelligibility, 1000 cps 26 per cent and 2000 cps 70 per cent.

Audiograms of profoundly deaf children generally show more severe losses in the higher frequencies than the low, and at the same time the latter contributes the greater amount of information for speech perception. Within a group of deaf subjects those who have less severe losses in high frequencies should make higher speech perception scores. This seems to be confirmed by the data of this study.

To illustrate the effect of the degree of hearing loss at the higher frequencies on auditory speech perception, Figure 6 shows the hearing loss curves of two S's represented on a standard audiogram form. The two S's average loss for 500, 1000 and 2000 cps are approximately equal, i.e., subject 10, although having a greater loss at the lower frequencies, 250 and 500 cps, has more hearing at the higher frequencies, 1000, 2000 and 4000 cps, than subject 15. It is S 10, whose hearing loss at the higher frequencies is least, who makes substancially greater use of audition in speech perception. The speech perception scores of S 10 and 15 are 16 and 7 respectively.

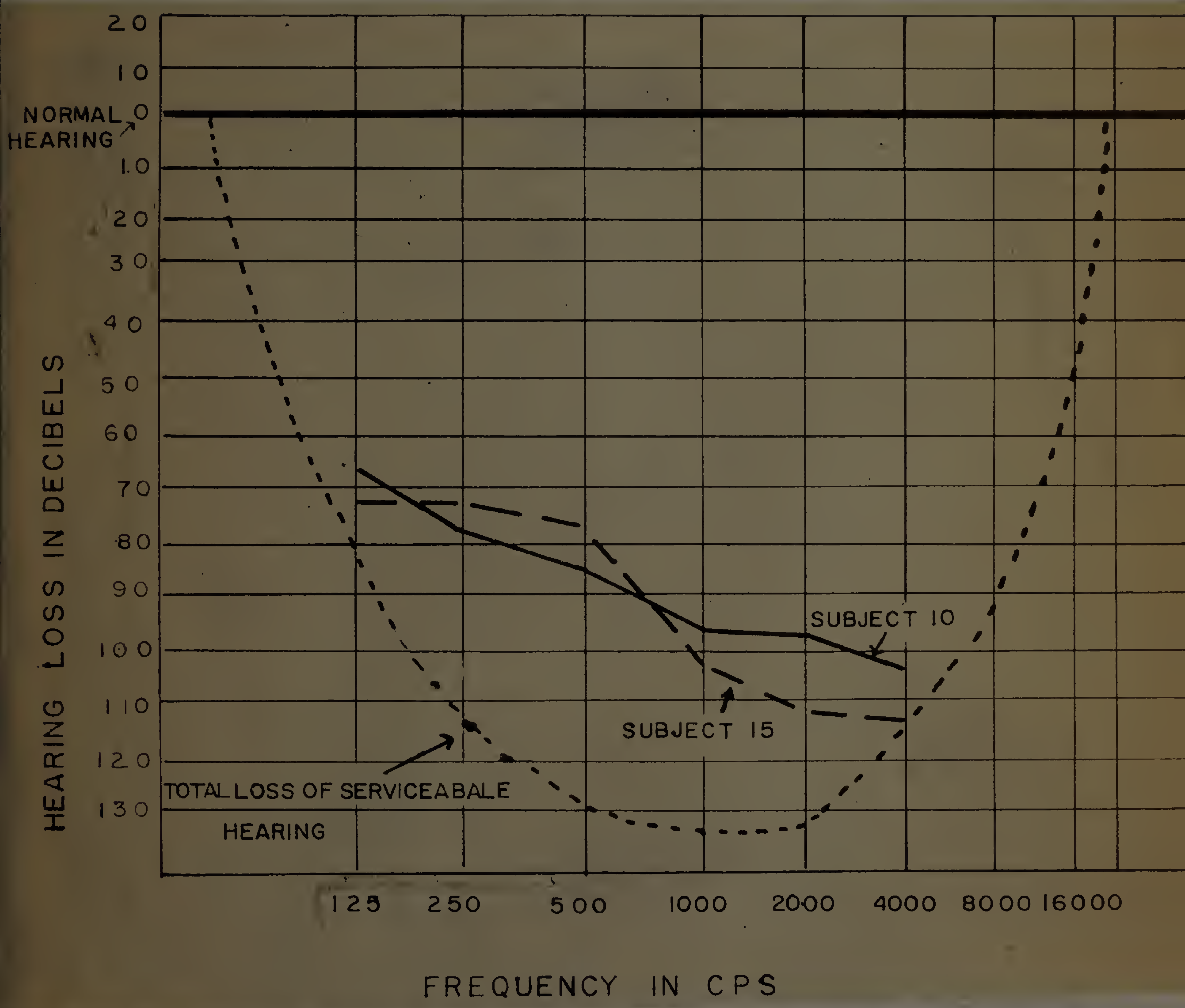


Fig. 6. Audiogram of two subjects showing hearing losses at 500, 1000 and 2000 cps which differ in the lower and higher frequency ranges, respectivdly.

<u>Frequency Discrimination and Auditory Speech Perception</u>

A statistically significant correlation (.01 level) was found relating frequency discrimination ability at 500 cps to the auditory speech perception scores. No significant correlations were found between frequency discrimination ability at 1000 and 2000 cps and auditory speech perception. Thus, those S's who have the greatest ability in discriminating frequency at 500 cps also make the greatest use of audition in the perception of speech.

The fact that frequency discrimination at 500 cps is correlated with auditory speech perception, while hearing loss at 500 cps is not, appears on the surface to be contradictory. This seeming inconsistency can perhaps be understood and resolved by an examination of the spectrum of speech. The speech spectrum as reproduced from Hirsh (6) is shown in Figure 7.

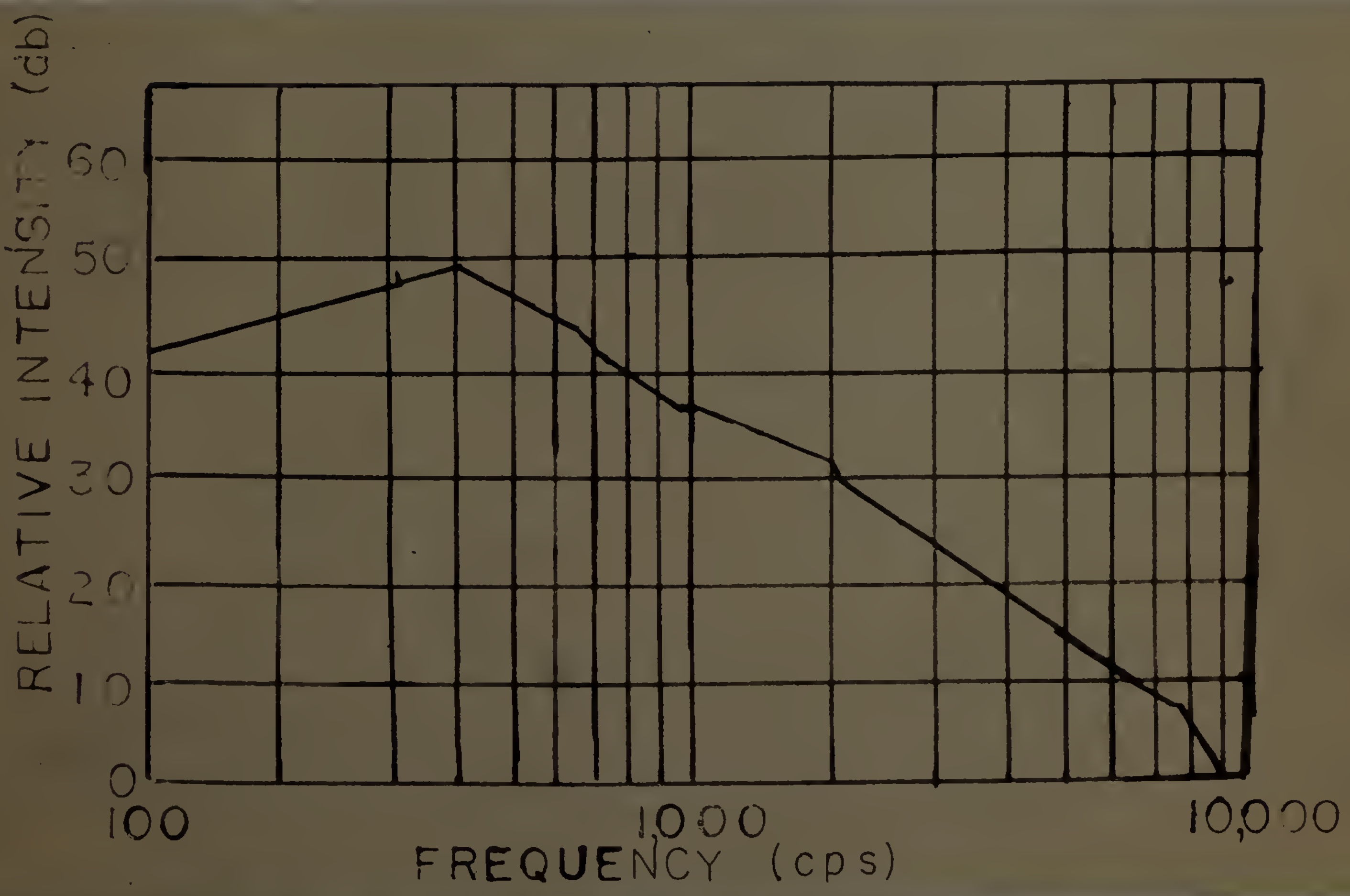


Fig. 7. Spectra for speech in terms of intensity per cycle.

As can bee seen from Figure 7, the maximum energies of speech lie in the lower frequencies below 700 cps and fall rapidly in the higher frequencies. It is also true that in the group of S's studied, the hearing losses are least in this lower frequency range and increase rapidly in the higher frequencies. Thus, the amount of auditory stimulation, the "deaf" ears receive from the higher speech frequencies is quite small and would be dependent upon the severity of the loss at the higher frequencies. Thus, it is understandable that those S's who have greater ability in low frequency pitch discrimination. The frequencies which carry the maximum energies of speech, are the ones who do the best in auditory speech perception. The fact that no correlations were found between the higher frequency discrimination for 1000 and 2000 cps, and auditory speech perception can be attributed to the fact that these frequencies carry a great deal less speech energy. In speech, these higher frequencies presumably carry so little of the total energy available to the deaf ear that their ability to discriminate pure tones at these frequencies, will above threshold, becomes valueless to them in the perception of speech. Thus, the amount of hearing at 500 cps alone tells us little about the severity of the loss in general and is therefore unrelated to auditory speech perception. At the same time the ability to discriminate frequency at 500 cps, around which the maximum energy for speech is found, is highly correlated with speech perception.

Hearing Loss and Frequency Discrimination Ability to Auditory Speech Perception.

Significant r's were found when multiple correlations were computed relating both hearing loss and frequency discrimination ability at 1000 and 2000 cps to the auditory speech perception scores. Thus, when hearing loss and frequency discrimination ability are correlated with auditory speech perception, those S's who have the least hearing loss at 1000 and 2000 cps and are best able to discriminate frequency at 1000 and s000 cps, also use the auditory component of speech perception to the greatest extent.

Although these correlations were statistically significant, they are somewhat lower than the correlations of hearing loss alone at 1000 and 2000 cps to auditory speech perception. Thus, the significance of these multiple correlations are due to the relationship between hearing loss and auditory speech perception at 1000 and 2000 cps; and the low and statistically non-significant correlations between frequency discrimination ability and auditory speech perception at 1000 and 2000 cps actually resulted in decreasing the multiple r's.

It would seem from the results of these multiple correlations that a knowledge of hearing loss at 500 cps and frequency discrimination ability at 1000 and 2000 cps would not yield additional information in regard to auditory speech perception. It is the frequency discrimination ability at 500 cps and the hearing loss scores at 1000 and 2000 cps which are significantly related to auditory speech perception. The addition of the hearing loss score at 500 cps or the frequency discrimination score at 1000 and 2000 cps merely results in a lowering of these relationships.

## Summary

Studies of frequency discrimination on normal ears have been going on for a great many years and by use of a wide variety of experimental procedures. While a great amount of data have accumulated over the years in regard to difference limens for frequency with normal hearing subjects it has been only quite recently that some interest has developed in the examination of frequency discrimination ability of "deaf" ears.

The present study measured the degree of hearing loss for twenty, either "partially" or "profoundly" deaf pupils at the Clarke School for the Deaf. The measure of hearing loss for pure tones was determined by the standard psychophysical method of "limits". Measures of these subject's frequency discrimination ability for three pure tones, 500, 1000, and 2000 cps, were made by a modification of the psychophysical method of "constant stimuli differences". Measures of auditory speech perception were also obtained for each of the twenty subjects.

It was found that the deaf subjects were able to make fairly consistant judgments of frequency differences for pure tones although their thresholds of discrimination were very large as compared to that of normal hearing subjects. In the group studied a wide range of difference limens for frequency were found.

No significant correlations were found between the degree of hearing loss and the difference limens for frequency at any of the three frequencies studied. This indicates that the severity of deafness is not related to frequency discrimination ability which may possibly be a function of some qualitative aspect of the remnant of hearing rather than the degree of deafness as determined by the audiogram.

Significant correlations were found to exist between the degree of hearing loss at both 1000 and 2000 cps and the measure of auditory speech perception. Thus, the less severe the deafness at the higher frequencies, which is generally more severe in the high frequency range for "deaf" ears, the greater is the use that can be made of audition in the perception of speech.

A significant correlation was found to exist only at 500 cps between frequency discrimination ability and auditory speech perception. This relationship indicates that these subjects who have the greatest ability to discriminate frequency at 500 cps also made the most use of audition in the perception of speech. A possibly explanation of this fact lies in the nature of the normal speech spectrum itself. It is a well established fact that the maximum energies of speech lie in the lower frequencies below 700 cps. It is a lso at the lower frequencies that hearing is least damaged in deaf ears. Thus it may be said that the low frequencies are available to the greatest extent for auditory speech perception in profoundly deaf children, and that their ability to discriminate frequency in this area is of greater significance than a similar ability in the higher frequencies.

Multiple correlations relating both hearing loss and frequency discrimination to auditory speech perception were statistically significant at 1000 and 2000 cps. Although both of these multiple correlations were significant they were lower than when frequency discrimination at 500 cps and hearing loss at 1000 and 2000 cps were correlated alone to auditory speech perception. This indicated that the multiple correlation of the two variables did not supply additional information which would increase the probability of prediction of auditory speech perception ability.

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Appendix 1

Hearing Loss for Pure Tones, in Decibels, at 500, 1000, 2000 cps
And the Average Hearing Loss Scores for Twenty Deaf Subjects

| Subject Number | HL 500 cps | HL 1000 cps | HL 2000 cps | Average Loss |
|---|---|---|---|---|
| 1 | 73 | 74 | 60 | 69 |
| 2 | 59 | 77 | 91 | 76 |
| 3 | 59 | 87 | 91 | 79 |
| 4 | 79 | 95 | 92 | 89 |
| 5 | 87 | 94 | 89 | 90 |
| 6 | 75 | 93 | 106 | 91 |
| 7 | 75 | 89 | 110 | 91 |
| 8 | 88 | 96 | 90 | 91 |
| 9 | 70 | 94 | 111 | 92 |
| 10 | 84 | 97 | 98 | 93 |
| 11 | 82 | 77 | 120 | 93 |
| 12 | 87 | 98 | 98 | 94 |
| 13 | 80 | 102 | 104 | 95 |
| 14 | 81 | 98 | 109 | 96 |
| 15 | 77 | 101 | 112 | 97 |
| 16 | 84 | 101 | 107 | 97 |
| 17 | 83 | 99 | 110 | 97 |
| 18 | 87 | 104 | 103 | 98 |
| 19 | 89 | 104 | 106 | 100 |
| 20 | 89 | 104 | 111 | 101 |
| Mean | 79 | 94 | 101 | 91 |
| Standard Deviation | 8.2 | 8.5 | 12.1 | 7.5 |

Appendix 2

The "Look and Listen", Lip-Reading, and "Difference" scores in Terms of Per Cent of Words from Standard Lists Correctly Perceived for Twenty Deaf Subjects

| Subject Number | "Look and Listen" | Lip-Reading | "Difference" (Auditory Speech Perception) |
|---|---|---|---|
| 1 | 92 | 64 | 28 |
| 2 | 94 | 74 | 20 |
| 3 | 89 | 62 | 27 |
| 4 | 63 | 55 | 8 |
| 5 | 82 | 76 | 6 |
| 6 | 51 | 45 | 6 |
| 7 | 44 | 40 | 4 |
| 8 | 59 | 49 | 10 |
| 9 | 47 | 43 | 4 |
| 10 | 85 | 69 | 16 |
| 11 | 52 | 47 | 5 |
| 12 | 58 | 51 | 7 |
| 13 | 43 | 39 | 4 |
| 14 | 32 | 29 | 3 |
| 15 | 63 | 56 | 7 |
| 16 | 57 | 49 | 8 |
| 17 | 46 | 46 | 0 |
| 18 | 48 | 45 | 3 |
| 19 | 56 | 47 | 9 |
| 20 | 56 | 50 | 6 |

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Approved by

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